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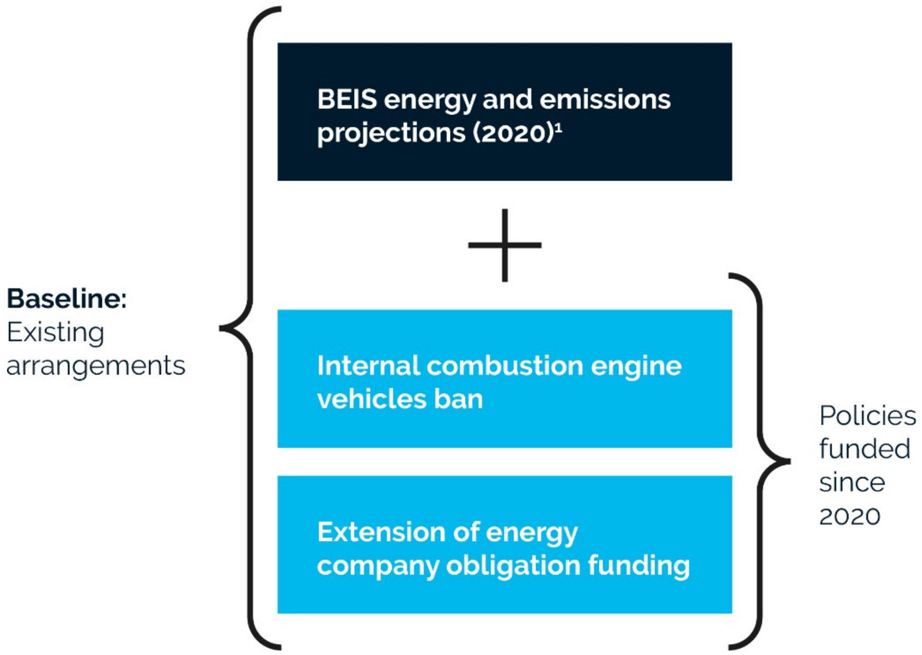
1. Baseline carbon emissions

We set a baseline based on BEIS Energy and Emissions Projections (2020) being fully delivered under the existing arrangements, as well as policies that were published ahead of the release of the Government's Net Zero Strategy.

Figure 1: Baseline modelling



The business-as-usual (BAU) trajectory for city-scale production-based (PB) emissions, i.e. the carbon emitted either directly within the city region's boundaries or indirectly via electricity use (Scope 1 and Scope 2 in GHG Protocol for Cities). Our focus was on all greenhouse gases measured as the mass of CO2e.

1.1 Emissions data sources

Our starting point was historical local authority carbon emissions data. To develop a BAU trajectory, we projected emissions forward by utilising city-region-level population forecasts and national-level emissions scenarios:

- Local-authority-level carbon emissions data disaggregated among domestic, industrial and commercial, and transport sectors and various sub sectors is available from The Department for Business, Energy and Industrial Strategy(BEIS). Time period covered: 2005–2018.
- Both UK- and local-authority-level population projections are regularly updated by the Office for National Statistics (ONS).
- UK-level projections of emissions and the carbon intensity of electricity supply are also available from BEIS, covering both CO2 and other GHGs and disaggregated by nine sectors. Time period covered: 1990–2040.

1.2 Emissions projections

To develop a forecast of BAU emissions, we first matched the BEIS national-level emitting sectors to the city-region-level sectors, aggregating into clusters where necessary (see Table 1). Using these growth rates, we used the latest city-region-level, per capita emissions for each sector and projected them forward to 2050. We therefore assumed that the per capita growth rates in emissions at the city region level and national level are the same for each sector/cluster.

Table 1: National-level sectors from the BEIS emissions scenarios matched to the city-region-level, local authority emissions sectors

	National-level		City-region-level	
	Disaggregation	**Time frame**	**Disaggregation**	**Time frame**
Emitting sector	Agriculture Industrial processes Waste management Business Public	1990–2040	Ind' & Com' (other fuels)	2005–2018
	Energy supply		Ind' & Com' (electricity) Domestic (electricity)	
	Residential		Domestic (other fuels)	
	Transport		Transport	
	LULUCF		LULUCF	

We then explored city-region-level mitigation scenarios for emissions across the domestic, commercial and transport sectors. For each sector, we

- Identified a range of applicable low carbon measures.
- Assessed their per-unit investment costs and energy savings.
- Estimated their city-wide deployment potentials.

2. Financial costs and benefits and carbon reduction

2.1 Transport

Analysis focused on the intra-city transport most prevalent in towns and cities across the UK:
- Cars and taxis
- Heavy and light commercial vehicles
- Buses and coaches

The transport model was designed to estimate the costs, benefits and abatement potential of measures that would change current travel patterns. Estimating total emissions in the transport sector involved compiling emissions intensities for each mode of transport (CO_2e/pkm) and city-region-level mode share (pkms*) (see Figure 3).

First, we built a baseline based on existing travel patterns. Next, to build a scenario we induced changes to the transport system:
- Substitution of trips for different trips (Shift).
- Efficiency gains due to electrification (Improve).
- Reduced number of trips due to network/logistical efficiencies (Avoid; only use for freight).

Comparing the changes in distance travelled and energy used from the baseline based on what influenced the change, we attributed costs and benefits to each low carbon measure such as shifting journeys from small petrol cars to walking or the electrification of public buses.

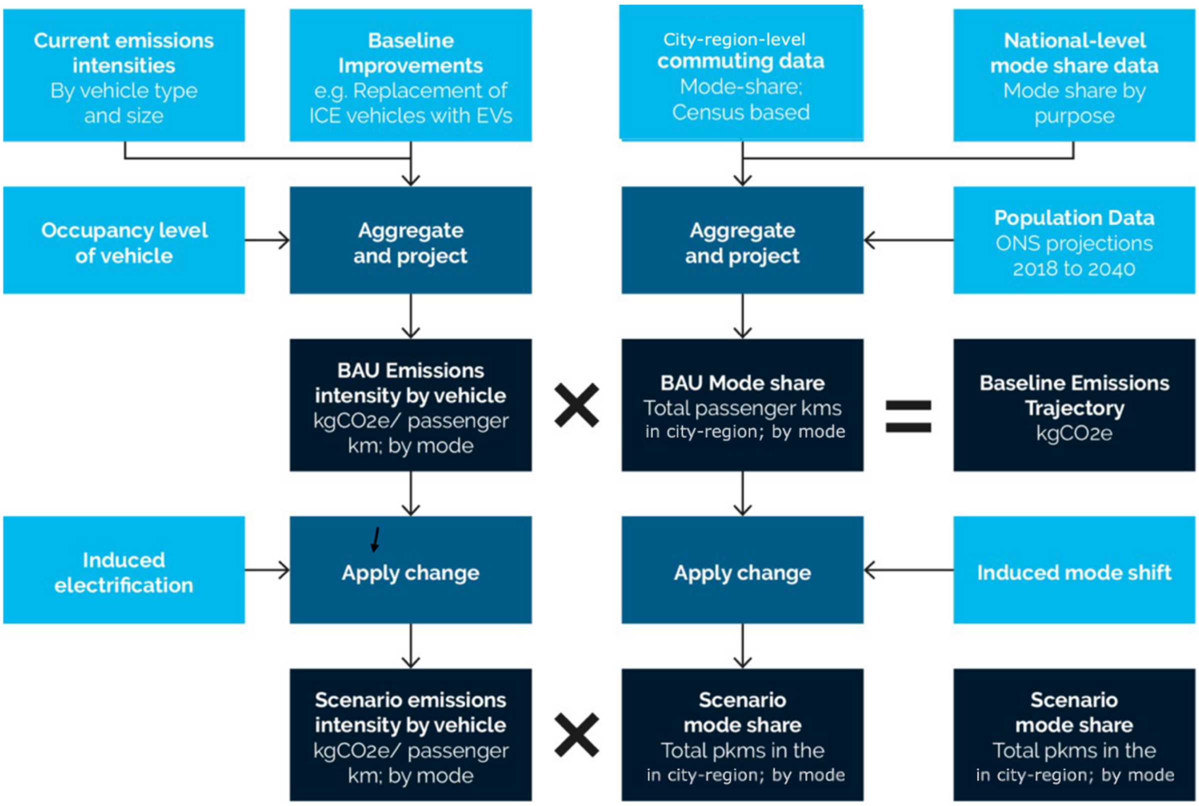


Figure 2: Flowchart outlining the transport sector methodology

In this study, rail, metro and tram travel were not considered. These modes make up 2% of journeys in most UK cities, (but 15% in London, which we did not model). We also excluded any changes to urban form because of the deployment of low carbon measures (e.g. decreased journey times leading to changes in trip lengths).

Table 2: Categories of low carbon measures in the transport sector

Category of low carbon measure	**Description**
Avoid	Improving the efficiency of the transport system, including integrated land-use planning and transport to reduce trip length
More efficient logistics	Improving efficiency of the logistics system by better route planning or combining trips for multiple purposes
Shift	Moving from the most energy consuming urban transport modes towards more environmentally friendly modes
Car trips to walking	Walking generates no emissions, so shifting reduces carbon emissions from trips otherwise taken by car.
Car trips to cycling	Cycling generates no emissions, so shifting reduces carbon emissions from trips otherwise taken by car.
Car trips to buses	Buses generate emissions, but lower energy consumption and higher occupancy mean emissions per passenger-km are lower than for cars.
Improve	Enhancing the energy efficiency of transport modes, taking advantage of alternative energy use
Electrification of private petrol and diesel vehicles	Petrol and diesel vehicles generate emissions on every journey, and electrification provides an opportunity for the energy used to be generated via renewable sources.
Electrification of distribution vehicles (HGV, OGV1 and OGV2)	Electrifying vehicles typically run on petrol or diesel provides an opportunity for the energy used to be generated via renewable sources.
Electrification of buses and coaches	Electrifying buses and coaches previously run on petrol or diesel provides an opportunity for some the energy used to be generated via renewable sources.

2.2 Financial costs and benefits

Costs and benefits were attributed to each low carbon mitigation measure by comparing the difference between the scenario and the baseline model runs to allow for system interactions. This difference in energy usage and/or distance travelled between the baseline and scenario models was used to estimate costs and benefits (calculated as net difference for each metric). Table 3 lists the costs and benefits analysed in this study. All costs are discounted at a rate of 3.5%, except for those related to logistics because they represent a cost directly to the private sector; a discount rate of 7% is used for logistics-related costs.

Table 3: Financial costs and benefits in the transport sector

Cost or benefit	**Title**	**Description**
Cost	Discounted capital cost—charging infrastructure	The cost of chargers is worked out based on the number of extra EV kilometres driven in each scenario.

Cost or benefit	Title	Description
	Discounted capital cost — vehicle purchase	The net cost of electric vehicles over ICE vehicles, extra buses required, and bike purchases.
	Discounted capital cost — infrastructure	The cost of extra bike lanes and bus lanes required based on a proportion of the extra bus riders and cyclists added.
	Discounted non-fuel operating costs (buses)	The extra operating costs associated with running buses—chiefly drivers' salaries. This metric is a cost in most city regions and scenarios since more bus journeys are required.
Benefit	Discounted non-fuel operating costs (all vehicles)	Maintenance, oil, and tyres for all vehicles. This metric is a benefit in most city regions and scenarios since higher maintenance of buses is offset by much lower maintenance costs for cars, both because there are fewer cars and because EVs are cheaper to maintain.
	Discounted energy savings	The net cost of energy required to power the new journey patterns. This metric is a benefit in all city regions and scenarios because electricity is cheaper than petrol or diesel, and walking or cycling is free.

2.3 Key inputs and assumptions

To estimate a city region's residents' travel activity, we used a combination of city- and region-level data. Trips per person by mode and region were derived from the National Travel Survey (2017–2019) and average miles by mode from the 2011 census. Trips were adjusted for the local region where city region level mode share data was available. Population data were derived from ONS projections.

Data from the Department of Transport 'Transport Analysis Guidance' were used for vehicle occupancy and proportion of work and non-work trips. Following the process outlined in the flowchart in Figure 3, these inputs provided pkm by mode over the period 2021–2050.

The GHG emission intensity and cost of different travel modes were estimated using national datasets. The proportion of cars by fuel source and fuel and non-fuel operating costs by vehicle type were drawn from the Department of Transport 'Transport Analysis Guidance'. Energy prices were drawn from BEIS 2020 Updated Energy and Emissions Projections, and vehicle emission factors were derived from the UK Government Emissions Factors for Company Reporting, excluding electricity grid emissions factor projections, which were derived from BEIS 2018 Updated Energy & Emissions Projections.

A notable assumption was that we assumed that it is possible to shift as much as ~40% of car trips onto buses or bikes under the current system. This figure of 40% came from maximizing the total average distance walked and cycled per capita at 5.2km based on the assumptions detailed below. The assumptions used to estimate a city region's residents' travel activity are provided in Table 4.

Table 4: Key assumptions in transport model

Metrics/Assumptions	Description	Source
Trips per year per person	Average number of trips taken per person per year by mode for that region.	Department for Transport Statistics - National Travel Survey - England: 2018/2019 (2 survey years combined).

Metrics/Assumptions	Description	Source
Distance travelled by mode annually	Average distance in miles travelled by mode annually across that region.	Department for Transport Statistics - Average miles travelled by mode, region and Rural-Urban Classification: England - All areas.
Total Oil Equivalent (TOE)	Total oil equivalent by transport mode was used to develop a baseline for motorised transport energy use in each local authority.	Total final energy consumption at regional and local authority level: 2005 to 2018. BEIS.
Maximum distance km cycling per person per day	2.7 km per person per day was assumed to be an upper limit for achievable cycling distance, based on levels achieved in Denmark.	https://www.regionh.dk/english/traffic/cycling/Documents/17751Cykelregnskab_UK.pdf
Maximum distance km walking per person per day	2.5 km of walking per person per day was assumed to be an upper limit, based on a literature review.	https://www.nhsinform.scot/healthy-living/keeping-active/activities/walking
Distance per year per vehicle	Kilometres per vehicle (and by vehicle type) per year was held constant across cities and across time. If a scenario shifted trips to motorised transport, then the number of new vehicles was determined using the number of additional kilometres by that vehicle type divided by the average annual kilometres by that vehicle type.	Transport Statistics for Great Britain. Department for Transport.
Fast chargers per BEV	One fast charger for 80 battery electric vehicles and one for every 5 goods and/or transit vehicles.	Nicholas, M. and Hall, D., 2018. Lessons learned on early electric vehicle fast-charging deployments. International Council on Clean Transportation, Washington.
% trips by mode (2018 post only)	Total final energy consumption at regional and local authority level: 2005–2018 (BEIS) was used to determine travel by motorised vehicles. To estimate travel by non-motorised modes, NTS0103 was used to estimate the number of per person trips by bicycle and on foot. These values are regional and available only for English regions; as a consequence, assumptions were made for cities in Wales, Scotland and Northern Ireland.	NTS0103: Average number of trips by main modes - index: England.
Average trip distance	Average trip distances are assumed to be the same across cities.	NTS0105: Average distance travelled by main modes - index: England.
Changes to urban form	We have assumed that the urban form of a city-region stays static, meaning that average trip lengths by mode remains constant. This assumption means that any major infrastructure projects that could drastically change the way we travel were not accounted for.	
Occupancy	Car and vehicle occupancies through 2036; values held constant from 2036 through 2050.	TAG Table A 1.3.3
Occupancy—buses	Alteration from TAG source, which increased occupancy of buses from 14 to 17 — this assumption was based on research undertaken by University of Leeds.	Source: Williamson, R. F., Sudmant, A., Gouldson, A., & Brogan, J. (2020). A Net Zero Carbon Roadmap for Edinburgh. Place-Based Climate Action Network: London, UK, 1-30.

Metrics/Assumptions	Description	Source
Proportion of car, LGV & other vehicle kilometres using petrol, diesel or electricity	The proportions drawn from this dataset were assumed to hold for all cities.	TAG Table A 1.3.9 Special consideration for Petrol/Diesel (set at 1%).
Vehicle energy use	Vehicle efficiencies were assumed to be the same across cities.	TAG Table A 1.3.11
Vehicle efficiencies	Data from the TAG is used in conjunction with academic literature to provide values for different vehicle sizes.	TAG Data Table A 1.3.11 And Chkaiban, R., Hajj, E.Y., Bailey, G., Sime, M., Xu, H. and Sebaaly, P.E., 2020. Fuel and non-fuel vehicle operating costs comparison of select vehicle types and fuel sources: A parametric study. In Pavement, Roadway, and Bridge Life Cycle Assessment 2020 (pp. 284-293). CRC Press.
Share of kilometres by vehicle size	This dataset includes subset data to split heavy goods vehicles into types and passenger vehicles into large, medium and small.	VEH0124: Licensed vehicles by make and model and year of first registration: United Kingdom.
GHG emission factors	Scope 1 emissions factors were drawn from BEIS conversion factors. For Scope 2 emissions the reference scenarios for electricity production and generation sources were used to generate a baseline and annual conversion factors.	Conversion factors 2021: full set (for advanced users). BEIS. Appendix J: Total electricity generation by source Appendix G: Major power producers' generation by source.
Measures that are large in scale and diverse in scope	Shared electric vehicles — Assumed that 10 EVs are replaced by an EV that is part of a shared scheme. This assumption is a modifier used in the integrated scenario, modifying costs only. Shared bike scheme — Shared bikes were assumed to be used at ten times the rate at which private bicycles were used. Therefore, the cost of a shared bike was 0.77 times the cost of a regular bike. This assumption is a modifier used in the integrated scenario, modifying costs only.	https://www.transportenvironment.org/articles/does-sharing-cars-really-reduce-car-use
Marginal capital cost per vehicle	The marginal cost of electric vehicle relative to ICE equivalent e.g. electric car to ICE car.	TAG Table A1.3.14
Cost per fast charger	Faster chargers were assumed to cost £75,000, based on literature and consultation. This cost was the same for all vehicle types.	Mathieu, L. "Roll-out of public EV charging infrastructure in the EU." Transport & Environment 7 (2018).
Cost per bicycle	£505—Accounting for both the average cost of a bike alongside new entrant hard accessories.	http://eprints.lse.ac.uk/38063/1/BritishCyclingEconomy.pdf

Metrics/Assumptions	Description	Source
Non-Fuel Resource Vehicle Operating Costs (NFOC)	The elements making up non-fuel vehicle operating costs include oil, tyres, maintenance, depreciation and vehicle capital saving (only for vehicles in working time). Following discussion with DfT, we noted that NFOC contains a large depreciation component. DfT guidance can be found at the link below, and the original document (1988) from which NFOC is derived is "Review of Operating Costs in COBA, EEA division of transport, 1990-91". This source shows that NFOC parameter a is made up of 36% oil, tyres and maintenance and 64% depreciation and that parameter b is 100% depreciation. Depreciation is a way of expressing capital costs on an annualised basis. Because our methodology is net, we only considered the additional capital costs of low carbon measures — e.g. an EV is X more expensive than an ICE car. This surplus is included in our capex calculations as an upfront cost and constitutes the only relevant capex for vehicles. Therefore, there should be no depreciation contained in any of our calculations. Therefore, for our calculations we used parameter a * 0.36 and did not use parameter b.	Table A 1.3.14: Non-Fuel Resource Vehicle Operating Costs https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.375.1581&rep=rep1&type=pdf
NFOC of electric vehicles	E-PSV, e-OGV1, and e-OGV were assumed to have half the operating costs of their ICE equivalents. Data from the academic literature were used to provide values for different vehicle sizes.	TAG Table A 1.3.14 And Chkaiban, R., Hajj, E.Y., Bailey, G., Sime, M., Xu, H. and Sebaaly, P.E., 2020. Fuel and non-fuel vehicle operating costs comparison of select vehicle types and fuel sources: A parametric study. In Pavement, Roadway, and Bridge Life Cycle Assessment 2020 (pp. 284-293). CRC Press.
NFOC for cars are assumed to remain constant independent of car sharing rates	It was assumed that all private vehicles have a utilisation for work at 18.2%.	Table NTS0409 from DfT (2019 table)
Additional NFOC for buses	Further NFOC to account for additional costs based upon the CPT index — it was assumed that for every £1 spent on fuel £4.88 is spent on driver's wages, other labour and staff costs and insurance claims.	https://www.cpt-uk.org/media/ca2iuq21/change-in-bus-coach-industry-costs-for-the-12-months-to-31-december-2019.pdf
Reference energy prices	Retail prices were assumed for all vehicles.	BEIS 2018 Updated Energy & Emissions Projections (Retail prices table)
Cost of buses lanes per km	Assumed cost of additional bus lane capacity at £250,000 per km.	Greener Journeys/KPMG (2017)

Metrics/Assumptions	Description	Source
Capacity of a bus lane	A reasonable planning-level capacity for a dedicated transit lane is 80 buses per hour.	https://nacto.org/publication/transit-street-design-guide/introduction/why/designing-move-people/#:~:text=A%20reasonable%20planning%2Dlevel%20capacity,through%20a%20single%20transit%20lane.
Cost of cycling interventions	Assumption of £0.98m per additional km of additional cycling infrastructure, based upon a mixture of schemes such as cycle superhighway, mixed strategic cycle routes and resurfaced cycle routes.	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742451/typical-costings-for-ambitious-cycling-schemes.pdf
Additional capacity of cycling infrastructure	Assumption that major shifts to cycling will require additional dedicated infrastructure to (a) handle additional bikes on the road (b) generate the interest and necessary shifts — given the high capacity of cycling infrastructure, as well as the option for cyclists to use roads and alternative infrastructure, there is a high degree of elasticity between the shift to cycling and additional infrastructure required.	https://www.sciencedirect.com/science/article/pii/S2352146516305403?ref=pdf_download&fr=RR-2&rr=863c4871aba34057

2.2. Buildings sector

The purpose of these models is to estimate the financial costs, benefits and abatement potential of applying a variety of low carbon mitigation measures across 13 building archetypes in city regions across the UK. The buildings' models have been separated into domestic and commercial sectors.

The methodologies for estimating annual carbon savings in the domestic and commercial sectors are outlined in Figures 4 and 5. Annual carbon savings per unit of each mitigation measure are multiplied by the number of units deployed in the mitigation scenario (per house in the domestic sector or per m^2 of floor-space in the commercial sector).

Per-unit carbon savings were obtained from the energy savings data we describe below and the associated emissions intensities. We also accounted for the interactions that occur when multiple low carbon measures are deployed within the same building, which can reduce the savings achieved in the case of, for example, solar photovoltaics and efficient lighting.

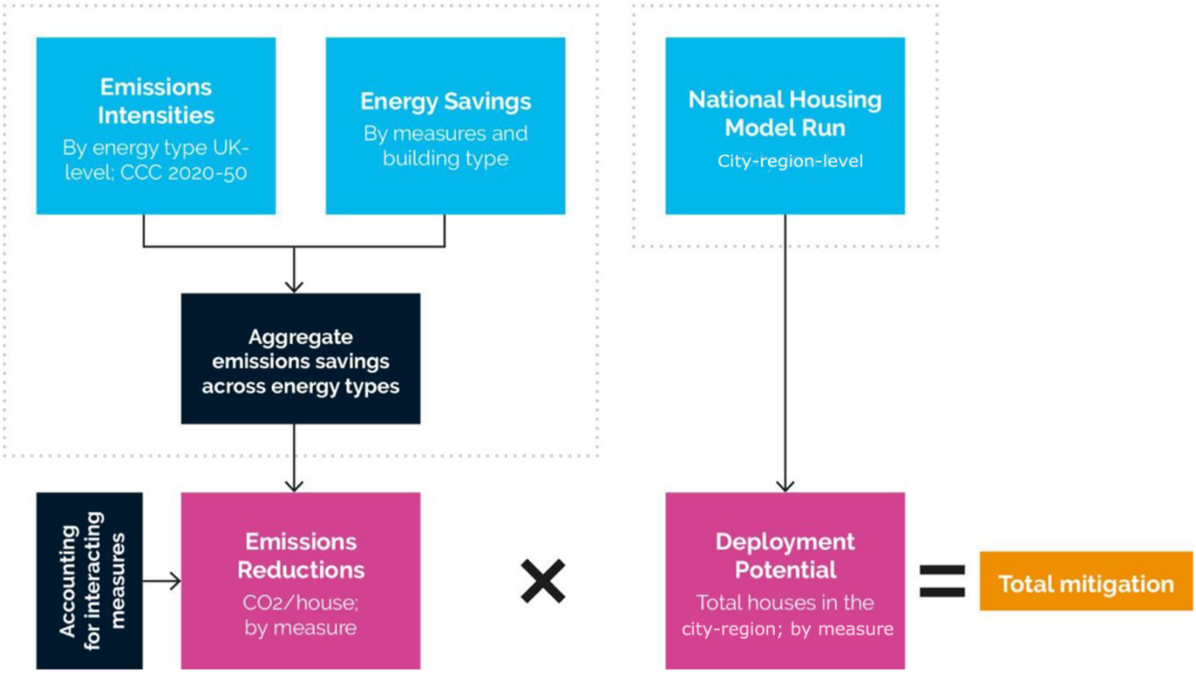


Figure 3: Domestic sector

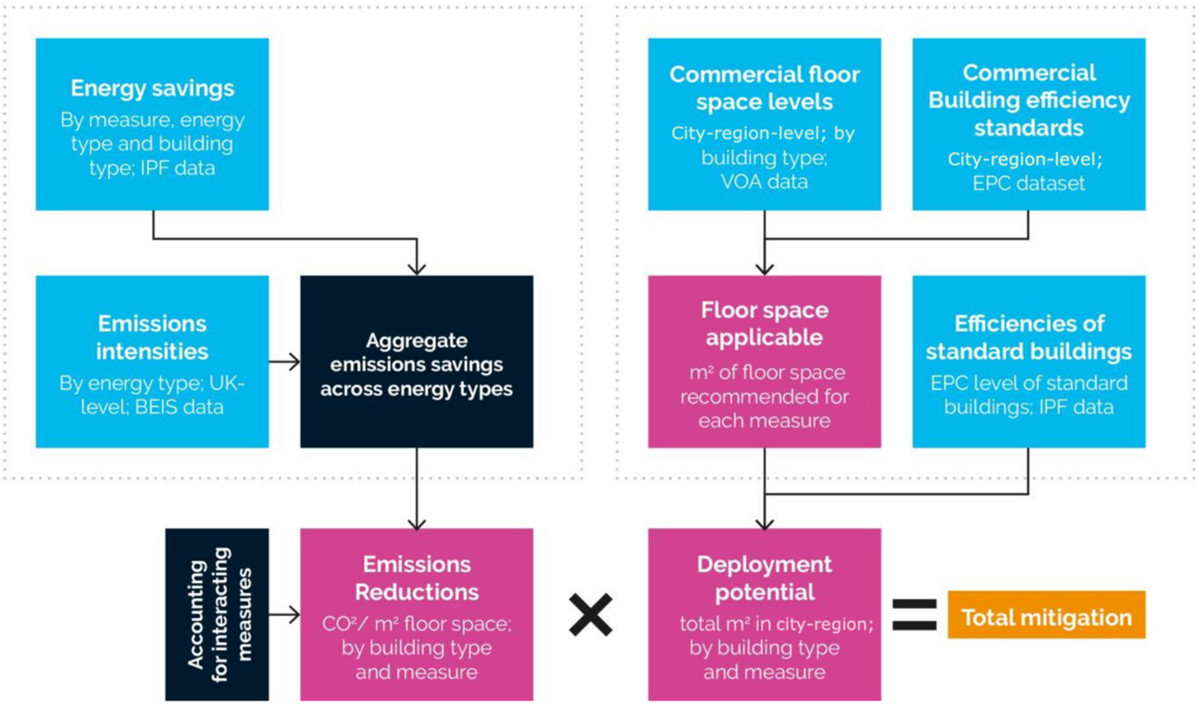


Figure 4: Commercial Sector

2.3 Low carbon mitigation measures by category

2.3.1 Domestic buildings

In the domestic buildings sector, low carbon mitigation measures were deployed on a per home basis across the following archetypes:

- Bungalows
- Converted built flats
- Houses (detached, semi-detached, end of terrace, mid-terrace)
- Purpose-built flats (high rise and low rise)

Table 5: Categories of low carbon measures applied to domestic buildings

Category of low carbon measure	Description
Energy efficiency	Upgrading gas ovens and appliances to energy efficient alternatives, gas hobs/stoves and ovens to induction alternatives, analogue to digital TVs, filament light bulbs to low energy lighting
Insulation	Increasing air tightness, replacing single with double glazing, adding external shading, improving insulation
Heating efficiency	Upgrading boilers to 95% efficiency, using heating controls, using heat recovery, increasing efficiency of technology (e.g. DC drive fan coils, chilled beams)
Low carbon heat	Installing solar thermal or replacing gas boilers with air source heat pumps
Microgeneration	Solar PV, installing a wind turbine
Scale and scope domestic measures	Area-based commercial PV installation, area-based commercial retrofit scheme

2.3.2 Public and commercial buildings

In the domestic buildings sector, low carbon measures were deployed on a floor area basis across six archetypes:

- Offices
- Retail space
- Industrial/warehouse units
- Community centres
- Education
- Healthcare spaces
- Hotels

Table 6: Categories of low carbon measures applied to public and commercial buildings

Category of low carbon measure	Description
Energy efficiency	Increasing energy efficiency of light bulbs, adding daylight and movement sensors, increasing efficiency of technology (e.g. variable speed pumps,

	chillers)
Insulation	Installing insulation (cavity wall, external wall, floor, internal wall, loft), draught-proofing, topping up loft insulation, installing triple glazing for windows)
Heating efficiency	Upgrading storage tanks and conventional boilers to gas combi-boilers, and installing tank insulation, thermostats, and radiator valves
Low carbon heat	Replacing storage tanks and conventional boilers with heat pumps, use of solar thermal
Behaviour change	Lowering thermostats, reducing heating for washing machines, reducing household heating by 10°C, reducing standby consumption, turning unnecessary lighting off
Microgeneration	Solar PV
Scale and scope commercial low carbon measures	Area-based commercial PV installation, area-based commercial retrofit scheme

2.4 Financial costs and benefits

Table 7 lists the costs and benefits included in our analysis. Costs were discounted at a rate of 3.5%. However, if a cost is directly applicable to the private sector (e.g. measures applied to retail units), then a discount rate of 7% was used.

Table 7: Calculated financial costs and benefits in the buildings sector

Capital cost	The capital costs of low carbon measures were estimated in net present value terms over the period from 2022–2050 taking into account: - When the new low carbon measure was assumed to be deployed. - The expected length of life of the low carbon measure before it requires replacement. Note — The total net present investment cost was applied on deployment between 2022 and 2030. Therefore, the cost of replacement was not realistically spread across the study period.
Energy savings	The deployment of each measure between 2022 and 2050 was multiplied by the estimated energy savings (for electricity, gas and other) associated with each low carbon measure multiplied by the discounted energy cost forecast from BEIS. As per BEIS Green Book guidance, we used long-run variable costs because energy prices include fixed costs that will not change in the long run with a small, sustained change in energy use; carbon costs, since these are valued separately; and taxes, margins, and other components that reflect transfers between groups in society.

Unlike in the transport model (where it was assumed that the price of EVs is likely to fall to reach parity with ICE cars by 2035), the cost of all buildings-related measures in this study stayed the same in real terms. The basis of this assumption is that most buildings measures, such as insulation and boilers, are very mature technologies and less likely to be subject to significant innovation.

2.5.1 Key inputs and assumptions

2.5.1.1 Domestic sector

For the domestic sector the list of low carbon measures, their lifetimes, and their costs and energy savings (electricity, gas, and other fuels) are consistent with the UK's National Housing Model (NHM), which was developed by the Centre for Sustainable Energy (CSE). It is worth noting that these costs have been tested and updated each time the models have been used by local authorities, most recently in 2020.

The (Energy Performance Certificate) EPC data sets represent the full housing stock by local authority, including information on current insulation levels, heating systems, etc. on a per property basis. Using EPC datasets in conjunction with these NHM outputs, we assessed what low carbon mitigation measures were appropriate for a particular city's domestic sector and for how many houses each measure would be suitable. This output is referred to as the deployment potential.

Using an s-curve deployment profile, each mitigation measure was deployed to its potential within the constraints set by the scenario. Therefore, we could calculate what energy and emissions savings would be expected, assuming the household maintains the same heating regime post-installation of each measure. The rebound effect has been accounted for; see Table 8. Also, the buildings stock was taken as static — i.e. we did not increase homes each year commensurately with likely house growth.

2.5.1.2 Public and commercial

In our model, the Public & Commercial buildings sector operates in largely the same manner as the domestic sector, although we changed the basic unit of analysis from individual homes to m^2 area of applicable non-domestic floorspace. For the commercial sector we obtained lists of low carbon mitigation measures and their lifetimes, costs, and energy savings (electricity and gas) from the review of the Investment Property Forum (IPF). these lists are appropriate throughout the UK. Mitigation measures were then assigned to different building types, with (marginal) costs and (multi-vectoral) energy savings detailed on a measure-by-measure basis.

To calculate city-region-level deployment potentials, we utilised data at the Local Authority (LA) level describing:

- Existing commercial floor-space by building type from the Valuation Office Agency (VOA).
- Energy Performance Certificate (EPC) assessments reported for commercial building stock across LAs.

We used these data sets together to estimate the floor space in a city region across each archetype. We assumed that the area of commercial floor space remains static across each of these archetypes. This assumption appears reasonable because, for the periods within which data were available, there were only negligible changes in the distributions of EPCs of commercial buildings and existing commercial floor space. We used the proportion of floor space surveyed in EPC assessments that recommended a particular intervention and applied this proportion to the total floor space in a city region.

Table 8: Key assumptions in buildings models

Metrics/Assumptions	Description	Source
Heat pump costs	Conducted a brief review of the Centre for Sustainable Energy (CSE) measures and inflated all to 2020 prices — all looked reasonable except for heat pumps—the deployment of this technology is potentially central to the transition and likely to be in high demand and, subsequently, in high supply. We found accurate up-to-date costs from the UK Government (see link) and used these costs to update the cost of heat pumps.	https://www.gov.uk/government/publications/cost-of-installing-heating-measures-in-domestic-properties
Heat pump cost reduction	Heat pump cost reduction has been applied in all scenarios in line with the Net Zero Strategy (NZS): The NZS stated that there is an ambition by the UK government to reduce the cost of heat pumps by at least 25% to 50% by 2025 and to reach price parity with gas boilers by 2030. Therefore, the price of an average heat pump used in the analysis would fall each year until 2030, when it would reach the same real price as an average gas boiler.	https://www.gov.uk/government/publications/net-zero-strategy
Heat pump deployment	Heat pump proportionality was assigned per population in each city region (based on the Government policy objective of 600,000 heat pumps provided each year from 2028 onwards), with deployment starting in 2022 and exponentially increasing to 2028, when 600,000 heat pumps would be deployed each year. The proportion of the original heat pump deployment across property types was calculated to split the updated deployment figure across property types.	
District Heat Network deployment	District heating networks currently supply 3% of the UK's heat supply: the aim is to increase the share to 20% by 2050. The Net Zero Strategy assumes that 6% of heating supply will be provided by district heating networks by 2035. To develop a deployment potential for district heat networks in the place agnostic scenario (i.e. not place-specific), proportionality was assigned per population in each city region in the same manner as heat pump deployment. Note: This deployment process means that heat networks were assigned to cities based on population but not based on the factors that actually will drive heat network deployment at the very local level: density, local heat sources and other local project feasibility factors.	
Deployment potential figures	The deployment potential for each low carbon mitigation measure for each property type was calculated for each city region based on EPC data; data was gathered on whether the low carbon measure could be deployed within a household and then aggregated up to the relevant low carbon measure group.	https://epc.opendatacommunities.org/
S-curve deployment of buildings mitigation measures	In all scenarios, it was assumed that deployment of building mitigation measures would start slowly in 2022 and would build to a peak in the late 2020s before tapering off. An S-curve was applied here rather than a linear growth rate.	

Metrics /Assumptions	Description	Source
Interactions methodology	We assumed that mitigation measures that impact the heating of a home will interact. Given that a household will use a certain amount of energy for heating, each low carbon measure will reduce the savings available for other measures. The following equations were applied to account for this adjustment: Corrected energy/carbon savings = original savings - original savings * (average house % savings w/o interactions - average house savings w/ interactions) Average house % savings w/o interactions = average number of interacting low carbon measures per house * average % savings per measure Average house savings w/ interactions = average savings per measure ^ number of low carbon measures Although cooling measures would also interact, the deployment is significantly lower for cooling low-carbon measures than heating measures, and so the impact would be negligible.	
Scale and scope of low carbon mitigation measures	- District heating networks — The cost and benefits were based on figures from a case study in Tallaght. - Whole house retrofit — measures that would be replaced by a whole house retrofit were summed and compared with desk research values. It was found that this output represented ~31% saving. This reduction was applied to other property types. The electricity, gas and other savings were reduced by approximately 10% overall. - Low energy apartment retrofit — the same method was used, and the same percentage reduction was applied. - Area-Based Commercial Retrofit Scheme — mean retrofit data comparing costs of typical schemes vs. individual low carbon measures for a range of commercial typologies (5) was used as a cost reduction on the sum cost of low carbon measures. - Area-Based Commercial PV Installation — the average values of the three existing low carbon measures was used, and a costing improvement from economies of scale data was used as a proxy for an area-based approach.	https://carbonneutralcities.org/wp-content/uploads/2018/05/1-London-Energiesprong-Transferability-Assessment.pdf; https://www.aecb.net/wp-content/uploads/2015/08/Going-Deep.pdf; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656866/BEIS_Update_of_Domestic_Cost_Assumptions_031017.pdf; https://www.codema.ie/images/uploads/docs/TDHS_Marketing_Brochure_for_Developers.pdf; https://www.hw.ac.uk/uk/schools/doc/egis/TARBASE_ND_REPORT.pdf; https://www.london.gov.uk/sites/default/files/appendix_a_solar_action_plan.pdf; https://www.theguardian.com/environment/2016/may/19/london-borough-installs-6000-solar-panels-on-market

Metrics /Assumptions	Description	Source
Rebound effect	For some domestic low-carbon measures (LCMs), an increase in energy efficiency would lead to increased use of energy to provide more comfort. We assumed a rate of 15% rebound for certain measures and valued this rate using BEIS guidance — see 'Home Comfort' on p. 25.	Committee for Climate Change (2013) — discussion of how the energy savings potential of low carbon measures (LCMs) is rarely reached because of in-use, comfort and inaccessibility factors. This analysis only considered comfort factors, but the context may be useful for further analysis. UK Energy Research Council (2007) — offering extensive evidence of the size of the rebound effect in different settings and concluding that "[t]he direct rebound effects were estimated to reduce overall energy savings by 15%."

3. Social costs and benefits

Besides their financial costs and benefits, each of the low carbon measures (LCMs) would create various wider social costs and benefits. These costs and benefits were identified and defined using impact pathways, drawing on the extensive existing literature that has considered the potential impacts of urban decarbonisation. Taken together, the financial costs and benefits plus the wider social costs and benefits provided our estimates of the net present social value (NPSV) of each low carbon measure.

Figure 6 summarises the key impact pathways identified in relation to the low carbon measures relevant to surface transport, and Figure 7 does the same for heat and buildings.

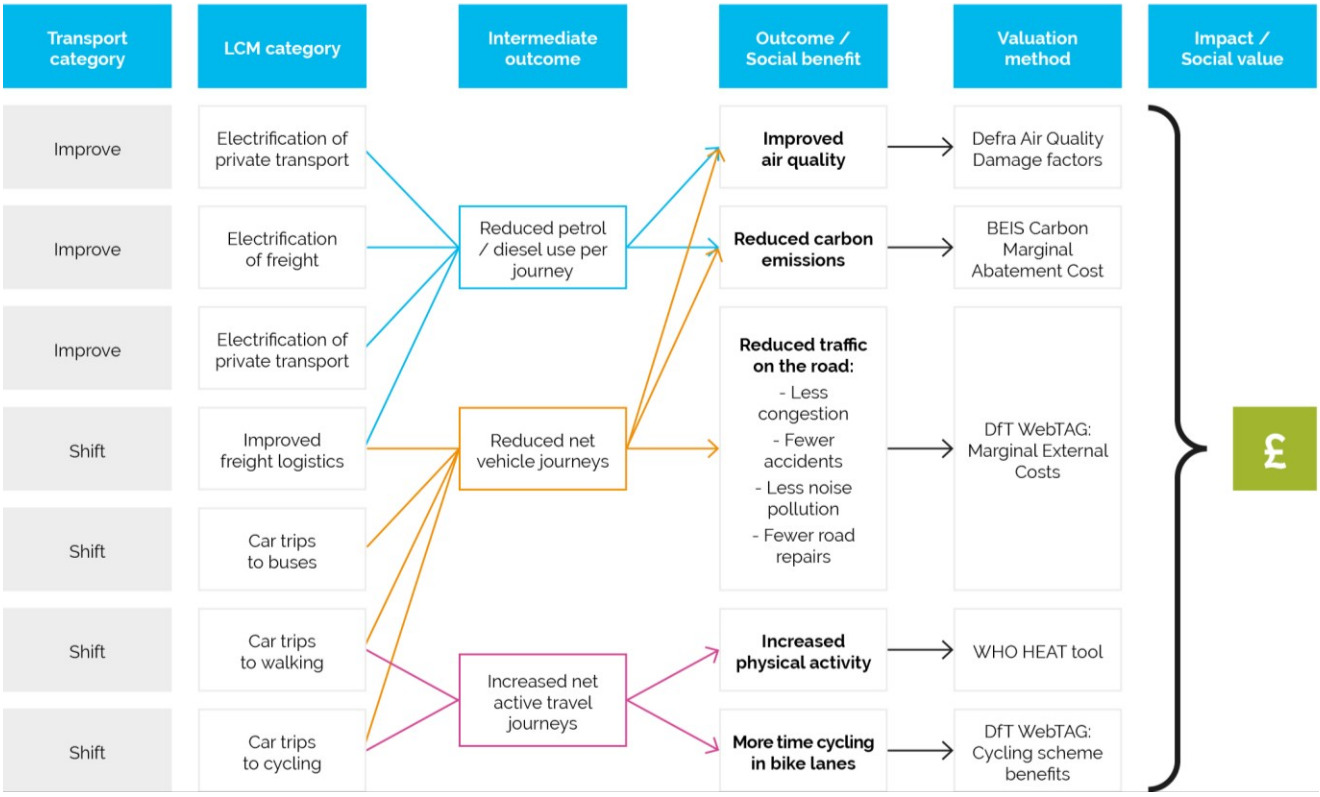


Figure 5: Simplified impact pathway for surface transport low carbon measures by category

All social benefits are presented as positive benefits (for example ‘improved air quality’ or ‘reduced congestion’). In aggregate, net benefits are generated under all scenarios, but they include both costs and benefits. For example, switching car trips to buses results in a benefit of fewer cars on the road, leading to reduced carbon emissions, congestion, and accidents. However, the impact of more buses on the road results in increased carbon emissions, congestion, and accidents.

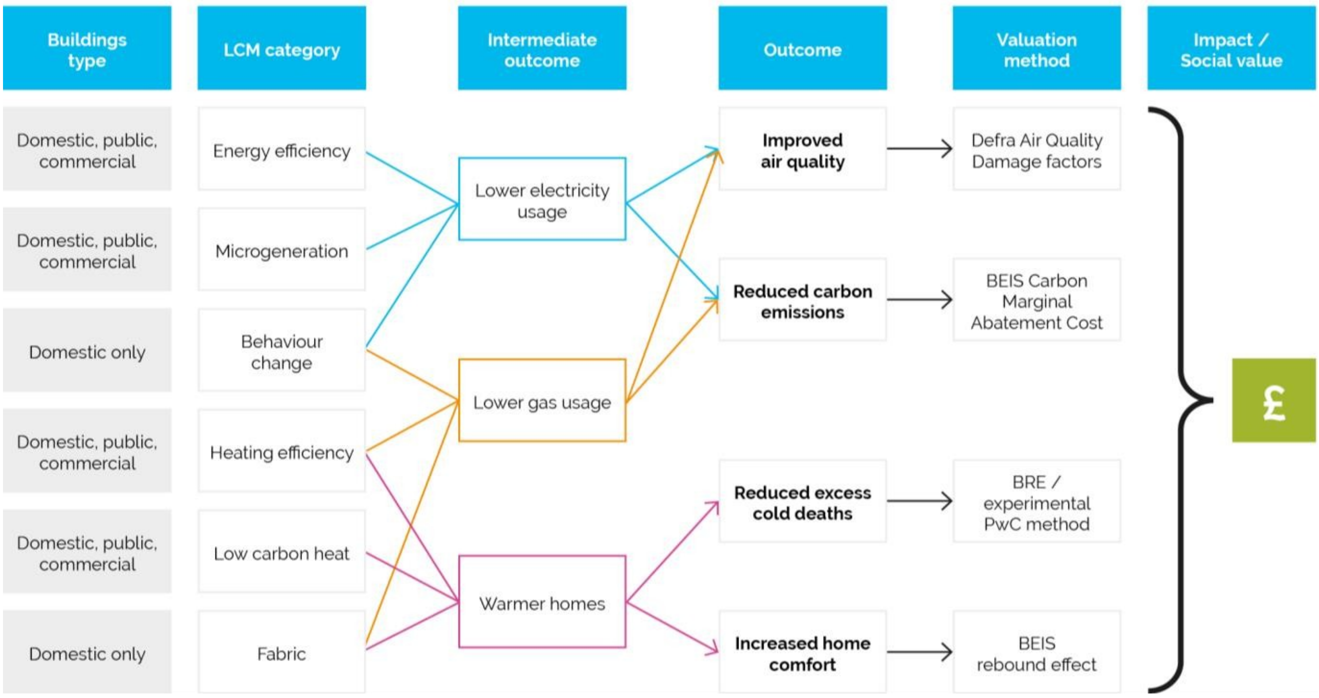


Figure 6: Simplified impact pathway for buildings low carbon measures by buildings type and category

Scale and scope low carbon measures are not shown; not all individual pathways are shown (e.g. some heating efficiency low carbon measures also would reduce electricity usage, but they would reduce gas usage far more because most UK homes have gas boilers).

3.1 GHG emissions

BEIS Valuation of greenhouse gas emissions: for policy appraisal and evaluation, updated Sep 2021, Annex 1, is the key source for the valuation analysis. As per BEIS guidance,

> Greenhouse gas emissions values ("carbon values") are used across government for valuing impacts on GHG emissions resulting from policy interventions. Carbon values represent a monetary value that society places on carbon dioxide equivalents (£/tCO2e). They differ from carbon prices, which represent the observed price of carbon in a relevant market (such as the UK Emissions Trading Scheme). The government uses these values to estimate a monetary value of the greenhouse gas impact of policy proposals during policy design, and after delivery.

3.1.1 Valuation methodology

(i) The annual net GHG emissions savings from the transport and buildings models are identified;
(ii) These emissions savings are multiplied by the carbon price for the appropriate year; and
(iii) The estimated benefits are discounted at 3.5% to derive their net present value.

By considering the change in use of different types of energy because of low carbon measures, it is possible to split the carbon values into traded and non-traded values. For example, as per BEIS guidance, electricity forms part of the traded sector, but domestic gas use is in the non-traded sector.

We do not present this analysis in our main findings or supplementary evidence because the updated guidance and further correspondence with the BEIS GHG appraisal team suggests that (i) the usefulness of this disaggregation in a broad, hypothetical appraisal such as this study is limited and (ii) the methodology is subject to change pending consultation on design of the UK ETS.

3.2 De-congestion benefits

Our assessment of the potential benefits of reduced congestion followed the approach recommended in the Department for Transport's WebTAG relating to Marginal External Costs, which builds on an academic paper from Samson et al (2001)[1].

MECs measure the change in social value in having one less car on the road because of different factors, as follows:

(i) Less congestion results in improved journey time and quality and lower vehicle operating costs;
(ii) Fewer accidents result in lower mortality and morbidity;
(iii) Fewer road repairs required equates to lower cost to the Exchequer;
(iv) Lower levels of noise pollution result in lower health and productivity burden;
(v) Fewer GHG emissions;
(vi) Lower air pollution; and
(vii) Lower road/fuel duty to the Exchequer.

Note that (v) and (vi) are valued elsewhere in our analysis (so not used here), and (vii) is a transfer from one group to another.

3.2.3 Valuation methodology

We used two sheets from the Tag MEC data — A5.4.1 (traffic data) and A5.4.2 (cost data).

3.2.3.1 Traffic data

The output from the transport models was vkms for different vehicle types per year, but these outputs were not split by

[1] Sansom T, Nash CA, Mackie PJ, Shires J, Watkiss P (2001) Surface Transport Costs and Charges: Final Report. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds

region or road type. Therefore, the first step required in the valuation methodology was

(i) Split total vkms in each city region into different region and road types.

This disaggregation was done using UK Government's DfT WebTAG Sheet 5.4.1: "Traffic by region, congestion band, area type & road type."

- Assumption: Regions are at the International Territorial (NUTS-1, i.e. Scotland, North-East, London); it was assumed that each city region has the same transport road usage as the region in which it is located. So, for example, Manchester and Liverpool both use North-West.
- Assumption: There is no regional split for Northern Ireland, so Wales was used instead because Swansea-Bay and Belfast city regions have similar levels of density.
- Assumption: DfT's regional road-usage splits (5.4.1) change every 5 years but stays constant between them.

This methodological approach allowed us to say that, for example, if 100km is driven by a car in Glasgow city region, then X% of it will be on an A road in an Inner conurbation. So, if 100km less is driven, then it will disappear from this same road/region.

3.2.3.2 Cost Data

DfT gives values in pence per vehicle kilometre (vkm) avoided, split by the mode, place and time the vkm is avoided, by:

- Vehicle type (Cars, LGVs, OGV, HGV and PSV)
- Year (2015–2050)
- Region (London, Inner and Outer Conurbations, Other Urban, Rural)
- Road type (Motorways, A roads, Other Roads)
- Congestion band (1 to 5; describes what % of the time each road is expected to be in free-flowing traffic (band 1) or standstill (band 5))

Vehicle type and year are outputs from the transport model, while region, road type and congestion band are calculated using web tag A5.4.1 above. For calculating costs the process is

(i) Use data and assumptions from section 3.2.3.1 above;
(ii) Multiply the avoided vkms per mode, place and time by the pence/vkm value for the corresponding mode, place and time; and
(iii) These benefits are discounted at 3.5%.

3.3 Air Quality

We assessed the value of the impacts on air quality using the damage cost guidance prepared by the Department for Environment, Food and Rural Affairs (Defra). The Defra approach considers different health impacts based on the latest advice from Public Health England and the Committee on the Medical Effects of Air Pollution (COMEAP). Three impact pathways were included in this valuation:

- public health
- the natural environment
- the economy

Detailed information on derivation of this methodology is available here.

3.3.1 Valuation methodology

There are two Defra tables — one for air quality damage from transport emissions and one for fuel combustion from buildings. Both assume that damage is higher when fuel is consumed in more densely populated areas. They also require the user to calculate where each unit of fuel is used. However, the two tables use different "density areas", as shown.

Table 9: Density areas used to assess air quality damage in buildings and transport

Buildings

National Average
Domestic: Inner Conurbation
Domestic: Urban Big
Domestic: Urban Medium
Domestic: Urban Small
Domestic: Rural

Transport

Transport Average
Central London
Inner London
Outer London
Inner Conurbation
Outer Conurbation
Urban Big
Urban Large
Urban Medium
Urban Small
Transport Rural

(i) Split each local authority in each city region into a transport and buildings density-area type. This disaggregation was done using either (depending on data availability):

- For buildings — The density of the LA was matched to ONS population stats, with each building's density area being assigned to a different density quintile.
- For transport — Allocations from Table 6 of the National Transport model, and, where these allocations were not present for a place, ONS density data was used (as per section 3.2.3.1).

* Note that neither of these methods have any relation to the splitting of vkms into road types in section 3.2.3.

(ii) Multiply the damage factors per fuel type, per year, per density area by the change in energy usage by fuel type per low carbon measure per year. For transport, the vehicle-type split is also required.

(iii) These benefits were discounted at 3.5%. In addition, there is no annual data series for transport air quality damage, so damage costs were inflated to 2022 prices and then 2% p.a. as per the Defra guidance.

- Assumption: Air quality (AQ) damage includes both health benefits and non-health benefits (i.e. changes to productivity); therefore, we used the discount rate of 3.5% and not the pure health benefits rate of 1.5%.

3.4 Physical activity

Our estimate of the health benefits associated with the change in levels of physical activity associated with adoption of different low carbon measures was based on the World Health Organisation's health economic assessment tool (HEAT). World Health Organisation - online Health Economic Assessment Tool (HEAT) for walking and cycling. The methodology was improved following correspondence with the authors, based on the academic paper that informs the methodology.[2]

[2] Götschi, T., Kahlmeier, S., Castro, A., Brand, C., Cavill, N., Kelly, P., Lieb, C., Rojas-Rueda, D., Woodcock, J. and Racioppi, F., 2020. Integrated impact assessment of active travel: Expanding the scope of the health economic assessment tool (HEAT) for walking and cycling. *International Journal of Environmental Research and Public Health*, *17*(20), p.7361.

3.4.1 Valuation methodology

Assumption: The academic paper (Kahlmeier et al., 2011[3]) that underpins the methodology assumes that health benefits only accrue to people between ages 20 and 74 for walking and between ages 20 and 64 for cycling since there is no evidence otherwise. We assumed that all extra vkms travelled by active travel are completed by these respective age groups for cycling and walking. This assumption is reasonable since:

- loss of life due to lack of physical exercise is very unlikely before age 20.
- frequency of exercise drops for those over age 75, who are half as likely to walk regularly and for those over age 65, who are three times less likely to cycle regularly than the population aged between 20 and 64.
- In addition, the age groups from Kahlmeier et al. (2011) are broken down further because the younger group (20-44) has a much lower risk of mortality — see step 5.

The steps are as follows:

(i) Our transport model estimates the extra vkms being walked and cycled per year;

(ii) Divide by the age grouping populations average walking/cycling speed (from HEAT; 14km/h) and 365 to give hours of exercise per person per year, assuming all people split the exercise evenly;

(iii) Use HEAT calculation: Divide the extra exercise per person in each age group by the reference range given by HEAT, and then multiply by the total reduction in risk that is associated with the reference range (see HEAT tool);

(iv) If the volume of exercise exceeds the capped amount, then cap. Note – this threshold is not reached in any of the modelled scenarios because the cap is equivalent to 450 minutes per week of cycling or walking;

(v) Multiply the reduction in risk for each age group by the total all-cause mortality for each age group in a given city region. This output gives the total number of mortalities per city region per year that would be avoided by increased physical activity;

(vi) Calculate the average number of life years remaining for each age group — e.g., older age groups are likely to live less long;

(vii) Multiply this output by the number of expected mortalities (5) and the Value of a Life-Year (VOLY) to give a total value of life lost per year;

(viii) Create a lag so that it takes 5 years to accrue total benefits, with 20% created in the first year, 40% in the second year, etc; and

(ix) Discount by 1.5%: We used the Green Book recommended discount rate for health benefits because they are pure health benefits.

3.5 Excess cold

Our estimates of the social costs and benefits associated with the avoidance of excess cold followed an experimental method based on evidence from Building Research Establishment (BRE) and Cambridgeshire County Council[4]. BRE estimated the potential NHS savings if 25 different housing hazards were eliminated in the UK. The largest hazard is "excess cold," which was estimated to cost the NHS £848m in 2015 (£1.4bn in 2020 prices). The approach set out below allocates a proportion of these potential savings to the successful deployment of low carbon measures that increase domestic warmth.

This approach is experimental, was designed for this study and should be used with caution because the causal pathway from improved housing measures to lowered likelihood of morbidity or mortality from excess cold is complex, and this study does not have sufficient data to draw a direct line from one to the other.

However, the assumptions used are conservative, and the resulting benefits do not contribute significantly to the overall

[3] Kahlmeier, S., Cavill, N., Dinsdale, H., Rutter, H., Gotschi, T., Foster, C., & Racioppi, F. (2011). *Health economic assessment tools (HEAT) for walking and for cycling* [Monograph]. World Health Organization. https://researchonline.lshtm.ac.uk/id/eprint/2572594/

[4] BRE (2015). Understanding the cost of Poor Housing to Health. Available from <https://www.gov.uk/government/publications/homes-and-ageing-in-england-understanding-the-cost-of-poor-housing-to-health>

benefits (excess cold benefits represent ~1-5% of all social benefits in any given city region/scenario).

- Assumption: The model does not contain information on income distribution, so it is assumed that all low carbon measures generate the same level of benefits, even though insulation in a poorer household would be more likely to eliminate excess cold.
- Assumption: Excess cold creates wider social costs through lost productivity and reduced utility (it is unpleasant to live in a cold home). This study did not consider the former at all, which is likely to be significant, but the latter is included in "Home Comfort" benefits (see next section).
- Assumption: This method assumes a direct link between temperature increase and health benefits and makes no provision for other impacts of temperature (e.g. (1) increased temperature may also decrease dampness, which has health benefits; (2) increased insulation may increase the likelihood of excess heat in summer, which has health disbenefits not considered in this study).
- Limitation — Despite their potential impact on reduced excess cold in UK homes in the future, increased temperatures resulting from climate change have not been modelled through to 2050 due to their unpredictability.

3.6 Valuation methodology

(i) Calculate the total value to the NHS of eliminating excess cold. Two datasets were combined:

- The BRE data showed that 60% of total NHS costs are due to excess cold (£848m of £1.4bn).
- The Cambridge Research Group data showed that the total cost to the NHS of all housing hazards is £2bn p.a.
- Therefore, we assumed that a cost to the NHS of £1.2bn p.a. can be associated with cold-related housing hazards that can be tackled by warming low carbon measures (60% x £2bn).
- This estimate is inflated to 2020 prices to give a figure of £1.43bn NHS costs.

(ii) Allocate NHS costs to city regions. Total NHS costs were split between city regions on a population basis but weighted for that city's experience of excess winter deaths in 2018/19 (i.e. pre-COVID).

- Assumption: Weighting NHS costs per city region by observed excess winter deaths: Excess cold deaths depend on many factors, including ambient winter temperature, housing stock and poverty levels of a city. In the absence of an analysis of these factors, we assumed that observed excess winter deaths in a city region could be considered indicative of them all.
- Assumption: Excess cold baseline: Analysis of long-term trends showed that excess winter deaths in the UK are falling by approx. 1% p.a. even as the population rises. This trend may be because of the factors mentioned above (warming temperature, improved housing), and it means that in the absence of low carbon measures NHS costs would be reduced over time. Therefore, this long-term trend was extrapolated and used to reduce the total amount of NHS savings available by ~1% p.a.

(iii) Allocate NHS costs to each low carbon measure deployed.

Domestic low carbon measures that increase heat were selected (67 out of 235).

- Assumption: Only low carbon measures that increase temperature imply 'anti-excess cold' health benefits — therefore, insulation was included but heat pumps were excluded.

The temperature increase of each low carbon measure was used to calculate a warming factor per low carbon measure using data from National Housing Model / SAP scores — see Standard Assessment Procedure - BEIS 2013.

- Assumption: There is a direct linear relationship between the extent to which a measure increases temperature and the extent to which that measure reduces NHS costs.
- Assumption: Measures that lower heat — thermostats, behaviour change — were assumed to not be deployed by households that are already cold; therefore, there was no excess cold disbenefit applied to those measures.

The warming factor was corrected by deployment potential so that 70% of max deployment equals 100% of NHS cost savings.

- Assumption: An assumption had to be made about whether total excess cold is fully eliminated when all possible EPC measures are deployed or at a lower level. This analysis assumed a level of 70%. This assumption was based on evidence showing that 37% of all homes surveyed in England have at least one significant hazard,[5] which means that the total NHS costs could be avoided if only those 37% of homes received warming low carbon measures. However, it is not possible to disaggregate at the household level so an assumption was made that once deployment reaches 70% of potential all the at-risk 37% would be covered.

Note: A more means-tested rollout of warming low carbon measures would generate higher NHS savings faster, but a more market-based approach (incentives to install insulation that incentivise richer households first) would likely result in a slower reduction in excess cold.

Use the corrected warming factor to assign a total £ value for each low carbon measure in each city. The total NHS costs can now be split between low carbon measures so that, for example, in an average bungalow cavity wall insulation installed between 1976 and 1983 is worth £140 p.a. in avoided NHS costs.

Multiply these £ values by the number of each low carbon measure deployed in each city region by scenario each year. Discount benefits at 1.5% (these benefits are pure health benefits and so are discounted at reduced rate).

3.6 Home comfort

This benefit follows BEIS guidance[6] on how to value the additional comfort that households receive from being able to use domestic appliances (e.g. heating, lighting) more when the energy efficiency of the appliances improves. This benefit values the "rebound effect". This effect is the extent to which energy efficiency measures result in households saving money on their energy bills, enabling them to afford to use these appliances more, leading to an improved quality of life (i.e. warmer, more well-lit homes).

From the domestic buildings model: the deployment of those low carbon measures where a reduction in energy usage (and therefore energy bills) may lead to higher usage (148 measures out of 235). For example, a more efficient oven is included but lowering a thermostat is excluded. Heat pumps are also excluded as they are more likely to increase fuel bills, so there would be no rebound effect.

- Assumption: In practice, the extent to which the rebound effect is present differs significantly, but a central rate of 15% was chosen for all measures.
- Assumption: 0% rebound effect was applied for public and commercial usage: the BEIS guidance gives some evidence that offices, schools, hotels, etc. are not constrained by energy prices to the same degree as households.
- Assumption: Indirect rebound effects are not considered at all — i.e. where money saved on energy is spent in the wider economy, increasing enjoyment.
- Assumption: Rebound rates remain at 15% throughout the study — there is no reduction over time thanks to exogenous changes to buildings standards or energy prices.

3.6.1 Valuation methodology

(i) Select domestic buildings low-carbon measures (LCMs) that are subject to a rebound effect;
(ii) Select the type of energy usage to which the rebound would be applied: For example, triple glazing results in gas savings (boiler usage) but not electricity savings, so the rebound effect applies only to gas; low-energy lighting only affects electricity use; a gas combi-boiler saves both electricity and gas;
(iii) Calculate 15% of the energy savings for each measure each year in kWhs;
(iv) Multiply the per-unit energy savings by the number of measures deployed each year and by the retail price of that measure.

- Assumption: Analysis of costs in this study always used the long-run variable cost of energy, but the rebound effect used the retail price. This methodology follows BEIS guidance: because the retail price is the price households pay to increase their heating or lighting; it is therefore a revealed preference of their willingness to pay for this experience.

(v) Benefits were discounted at 3.5%.

3.7 Bike lane ambience

We followed Department for Transport guidance on the extra journey quality a cyclist receives when cycling in a bus lane,

[5] https://files.bregroup.com/bre-co-uk-file-library-copy/filelibrary/pdf/87741-Cost-of-Poor-Housing-Briefing-Paper-v3.pdf
[6] Valuation of energy use and greenhouse gas: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government (October 2021)

as opposed to an open road. When cycling in a bus lane, cyclists feel safer and have less-interrupted journeys. Many cyclists would be willing to pay a small amount for this extra benefit, and DfT has created a methodology that seeks to capture that value created.[7] Note, however, that the total value of this measure is small (<1% of all social benefits), and in our main report and economic supplementary analysis we did not present it separately but as a part of physical activity benefits — but the methodology used was distinct from the methodology used to estimate the social benefits of physical activity.

3.7.1 Valuation methodology

(i) Translate bike vkms into minutes spent cycling each year by dividing by average cycling speed (14 km/h);

(ii) Create a constant (17%) to understand how much of this time is spent in bike lanes by multiplying the assumed % of all kms spent in bike lanes by the assumed difference in speed in bike lanes versus the road.

- Assumption: 20% of all kms travelled are in bike lanes. There is very little data on what proportion of time cyclists spend in bike lanes versus the open road in UK cities, but 20% was assumed to be a reasonable level for non-London cities, primarily based on results from Dill and Gliebe (2008)[8]. Due to gaps in the literature, a more recent and UK-based estimate could not be found over the course of this analysis. However, given the insignificance of this valuation in terms of overall outputs (<1%), the assumption was deemed reasonable following discussions with governmental departments.
- Assumption: Cyclists travel 15% faster in bike lanes because of fewer interruptions. There is very little data on difference in speeds in bike lanes, but this assumption is similar to the moderate scenario found in Rayaprolu et al. (2018),[9] which posits greater speeds in bike lanes and cycle highways relative to road cycling, as a result of fewer interruptions from pedestrians and car traffic.

(iii) Multiply total bike minutes p.a. by this constant to give bike lane minutes p.a. for each city region/scenario;

(iv) Calculate the average benefit generated per minute of cycle lane usage by averaging the 5 types of bike lane given in WebTAG.

Assumption: This study assumed that a given level of bike usage would create demand for more cycle lanes but not what type of lanes. DfT provides values for time spent in (1) off-road segregated cycle tracks, (2) on-road segregated cycle lanes, (3) on-road non-segregated cycle lanes, (4) wider lanes, and (5) shared bus lanes. We assumed that journeys would be split evenly between all five and so used the mean value of 3.79 pence per minute.

(v) Multiply bike lane minutes p.a. by this value to generate total benefits; and

(vi) Benefits were discounted at a rate of 3.5%.

[7] DfT WebTAG A4.1.6: Value of journey ambience benefit of cycle facilities.
[8] Dill, J. and Gliebe, J., 2008. Understanding and measuring bicycling behavior: A focus on travel time and route choice.
[9] https://journals.sagepub.com/doi/epub/10.1177/2399808318797334